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DIVERSION FLOW THROUGH BUFORD DAM CONDUITS

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DIVERSION FLOW THROUGH BUFORD DAM CONDUITS

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SYNOPSIS

The Buford sluice and penstocks will be used to divert the Chattahoochee River during the construction of the dam. These conduits will flow partly full during most of the diversion period. A graphical method is outlined to show how the transition takes place from part-full flow to pressure flow in the conduits.

INTRODUCTION

When the Buford cofferdam is closed the entire flow of the Chattahoochee River will be diverted through the two 22-foot penstocks and the one 13.25-foot sluice. See fig. 1 for the layout and profiles of the conduits during the diversion period. The river will continue to flow through the three conduits until the earth dam has been raised to a sufficient height to permit the diversion of the entire flow through the sluice alone, at which time the two penstock head gates will be closed and construction will be started on the powerhouse.

During much of the diversion period the conduits will be flowing partly full. In connection with the calculation of discharge-capacity curves it was desirable to estimate the flow condition for which each conduit will pass from part-full flow to pressure flow and the manner in which this change will take place.

The Graphical Method

In these studies use was made of a graphical method previously developed for backwater calculations in open channels.[1,2] Since precise results were not needed, a simplified approach was adopted in which entrance, gate-slot, and transition losses are neglected. In this simplified analysis use is made of the function

$$F = \frac{1}{2ga^2} \tag{1}$$

The symbols used in this equation and others used later in this paper are defined as follows:

- **A** cross-sectional area of circular part of conduit.
- **a** area below the water surface in a cross section.
- **d** depth of water at center of cross section in conduit.
- **D** diameter of conduit.
- **E** energy level of reservoir, i.e., reservoir level plus head due to velocity of approach.
- **F** a function defined by equation (1).

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1. Engineering Manual, Civil Works Construction, Part CXIV, Chapter 9, Corps of Engineers.
2. Backwater profiles solved by Escoffier-Raytchine-Chatelain method, John R. Stipp, Civil Engineering, August 1953.

Fo a quantity defined by equation (2).
g acceleration of gravity.
L length of circular part of conduit.
n coefficient of hydraulic friction in Manning's formula.
Q discharge.
R hydraulic radius of circular part of conduit flowing full.
S slope of conduit.
z elevation above datum.

The subscript c is used to identify the cross sections in the circular part of a conduit, and the subscript s, the cross section at the service gate.

The function F is plotted as the abscissa in a graph in which the ordinate is the water-surface elevation z. Some of the properties of the F function are shown in fig. 2 and the use of F functions to determine water-surface profiles in open channels in which energy losses are negligible is illustrated in figs. 3 and 4. In fig. 2 the line EN which has a slope of $-Q^2$ determines by its intersections with the F curve the two alternate depths which correspond to the energy level E. The lower alternate depth corresponds to flow at supercritical velocity and the upper alternate depth to flow at subcritical velocity. Since EcNc is the lowest position to which the line EN can drop and remain in contact with the F curve, Ec is the minimum energy level for the discharge Q and the point of tangency c represents flow at critical depth.

In fig. 3 there is shown an example of the use of F curves to construct a water-surface profile for flow through an open channel with neglibible losses in energy. The line EN is drawn tangent to the F curve for section 4 to represent flow at critical depth in that section. The intersections of EN with the remaining F curves determine the water-surface elevations in the corresponding sections.

Transition Levels

In fig. 4 there is shown an example of the use of F curves to construct water-surface profiles for flow through a reach of a non-uniform open channel with negligible losses in energy. To obtain the water-surface profiles shown in the diagram a number of F curves for intermediate sections were also used, but these have been deleted from the diagram in the interest of simplicity. It should be noted that the two F curves intersect at the level R. It should also be noted that the control for the water-surface profile above that level is located at the downstream end of the reach whereas the control for the one below that level is located at the upstream end of the reach.

The level represented by the intersection R of the two F curves in fig. 4 can conveniently be designated a transition level. Although the foregoing discussion relates to frictionless channels, transition levels also occur in channels which are not frictionless. In uniform channels they are the levels for which the normal velocity is equal to the critical velocity, i.e., the levels for which the channel slope is critical. A convenient diagram developed by Straub, Anderson, and Bowers[3] which can be used to determine transition depths in circular conduits is shown in fig. 5.

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3. This curve, the upper branch of which has been extended to include the range required by the Buford conduits, appeared originally in "Importance of Inlet Design on Culvert Capacity" by L. G. Straub, A. G. Anderson, and C. E. Bowers, Tech. Paper No. 13, Series B, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, (1953).

It is clear from fig. 5 that in a circular conduit there are either two transition points or none, depending on the value of the quantity $S_c / \frac{n^2}{D^{\frac{1}{3}}}$

If there are two, which is the case ordinarily met in engineering practice, then between these two depths the water-surface profiles have properties normally associated with a steep-slope channel, i.e., one with a slope greater than critical. If control by flow at critical depth takes place this will be at the upstream end of the conduit. For depths of flow less than the lower transition depth or greater than the upper transition depth the water-surface profiles have the properties normally associated with a mild-slope channel or one with a slope less than critical. In this case if control by flow at critical depth takes place this will be at the downstream end of the conduit.

Application to Conduits

The application of the foregoing concepts to a circular conduit is shown in figs. 6 and 7. Fig. 6 represents the Buford sluice and fig. 7, a hypothetical sluice. Two F curves are shown in each case, one to represent the circular section at the upstream end of the conduit, and one to represent the rectangular sections at the service gates. The point V on each gate curve represents the elevation of the vent which is located in each case immediately downstream from the service gate. The outlet-control point I which occurs in these diagrams is obtained by plotting the quantity

$$F_O = \frac{1}{2gA^2} + L\left(\frac{n}{1.486AR^{2/3}}\right)^2 \tag{2}$$

against the elevation of the crown of the conduit outlet. This point has been introduced to permit the representation of pressure flow in the diagrams. The vertical segments GH and KV have been added to the F curves for the same purpose. To represent pressure flow the construction line EN_2 is drawn through the point I and the intersections of that line with GH and KV yields the pressure gradient in the corresponding sections. The segment KV has not been extended below V because if the construction line EN_2 drops below V, air will be admitted through the vent and pressure flow will not occur.

In figs. 6 and 7 the line EN_1 has been drawn tangent to the curve that represents the upstream end of the circular part of the conduit. Since it is drawn tangent to the curve it represents flow at critical depth and the elevation of the point of tangency is the elevation of the water surface. This construction remains valid as long as the control remains at the upstream end of the conduit, i.e., as long as the point of tangency remains between the two transition depths. In practical use only the upper transition depth is of interest and that depth is conveniently represented in the diagram by the point T. In most of the conduits that occur in engineering practice there is no need to consider the possibility of the point of tangency rising above the upper transition depth because before this happens the water surface at the gate will rise high enough to block the air vent and cause the conduit to prime. In the exceptional cases where EN reaches T before the conduit primes a more complex graphical construction is required but that construction is beyond the scope of this paper.

The manner in which a conduit passes from part-full flow to pressure flow depends on the relative positions of the point I and a line MS drawn through the point V and tangent to the controlling F curve. Two cases will be distinguished, case 1 in which I lies below MS and case 2 in which it lies above.

The priming of the Buford sluice, which is a case 1 conduit, is shown graphically in fig. 6. The tangent EN_1 represents flow at critical depth in section c for the reservoir energy level E. However, since EN_1 lies above V no air can enter the conduit through the vent and the conduit starts to prime.

This would normally cause a rotation from EN_1 to EN_2 where the latter line has been drawn through the point I to represent pressure flow. However, the vent is uncovered in the process and air is again admitted into the conduit. A further complication arises from the fact that while the vent is blocked the pressure at section C is subatmospheric and an adverse pressure gradient exists in the conduit which opposes the movement of air bubbles toward the outlet. Neither EN_1 nor EN_2 represents a stable flow condition and the repeated attempts at priming give rise to pulsations which continue until the energy level E rises high enough to raise EN_2 above V or drops low enough to lower EN_1 below V.

A hypothetical conduit falling in case 2 is shown in fig. 7. The direction of rotation in priming, i.e., in going from part-full flow to pressure flow, is opposite to that in case 1. The line EN_1 represents flow at critical depth as before but now the vent is open and the required supply of air to permit that type of flow is available. The assumed flow is therefore stable. Similarly the line EN_2, which represents pressure flow is also stable since the vent is closed and no air is admitted to break the prime. The conduit will normally flow partly full on a rising reservoir until EN_1 reaches V at which time the supply of air is cut off and the conduit starts to flow under pressure. On a falling reservoir the conduit will continue to flow under pressure until EN_2 reaches V at which time air will be admitted and the conduit will start to flow partly full. It therefore appears that there exists a range of reservoir levels for which both types of flow are possible and stable and that the type of flow that takes place depends on the way in which the reservoir level in question has been approached.

The graphical construction for the penstocks is shown in fig. 8. The circular part of these conduits is composed of an upstream section that is horizontal and a downstream section that is sloped. Section c in this case is taken to be that at the break in slope rather than at the upstream end of the conduits. A section is also taken at the service gate. The energy losses between the two sections, which are small, are neglected.

The two curves intersect at R which is accordingly a transition level. The line MS has been drawn through the point V and tangent to the F_c curve as in the foregoing diagrams. The control shifts from the gate section to the circular section just before the energy level reaches M. This means that flow at critical depth remains at the gate until a short time before the conduit primes when it shifts to the circular section.

The point I which represents penstock No. 1 only, is slightly below the line MS and that penstock, therefore, falls in case 1. Since I is quite close to MS, the range of pool levels affected by pulsations will be small.

The proper location of I for penstock No. 2 is uncertain as the effect of the small branch penstock is difficult to evaluate. It is probable that the small penstock, together with the downstream part of the large one, will function to some extent as a draft tube. The result would be to shift I to the left and penstock no. 2 would also fall in case 1.

In summary, it appears that the sluice, penstock No. 1, and probably penstock No. 2, fall in case 1. They will therefore be subject to pulsations for some reservoir levels but as these pulsations will occur only during diversion no objectionable results are anticipated.

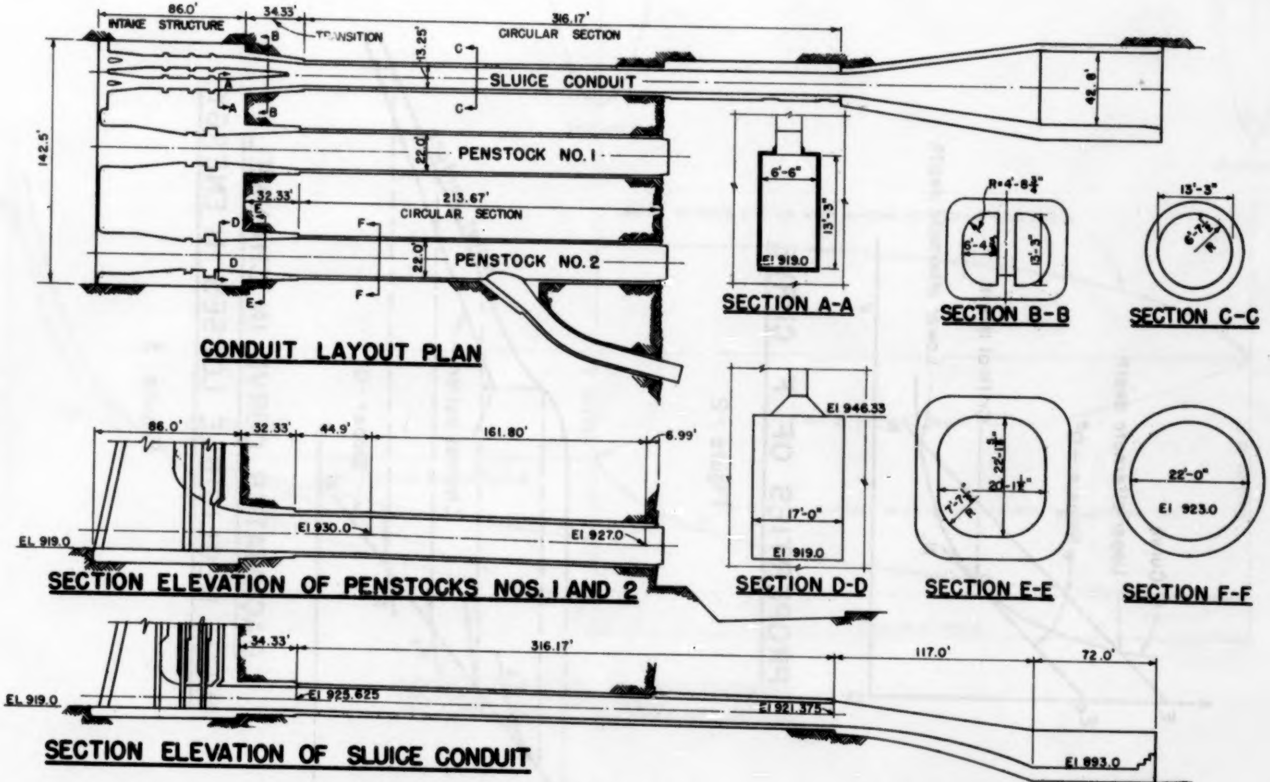
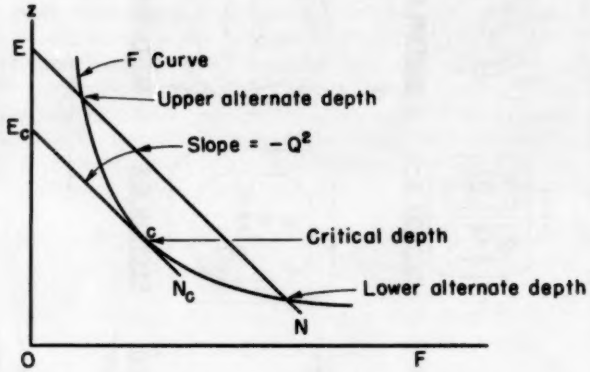


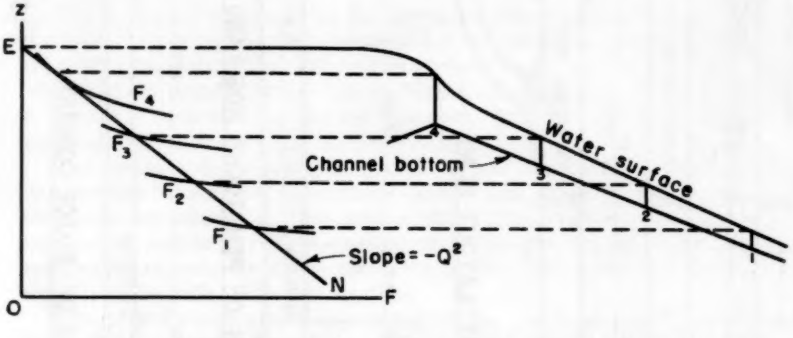
Figure 1

BUFORD DAM CONDUITS



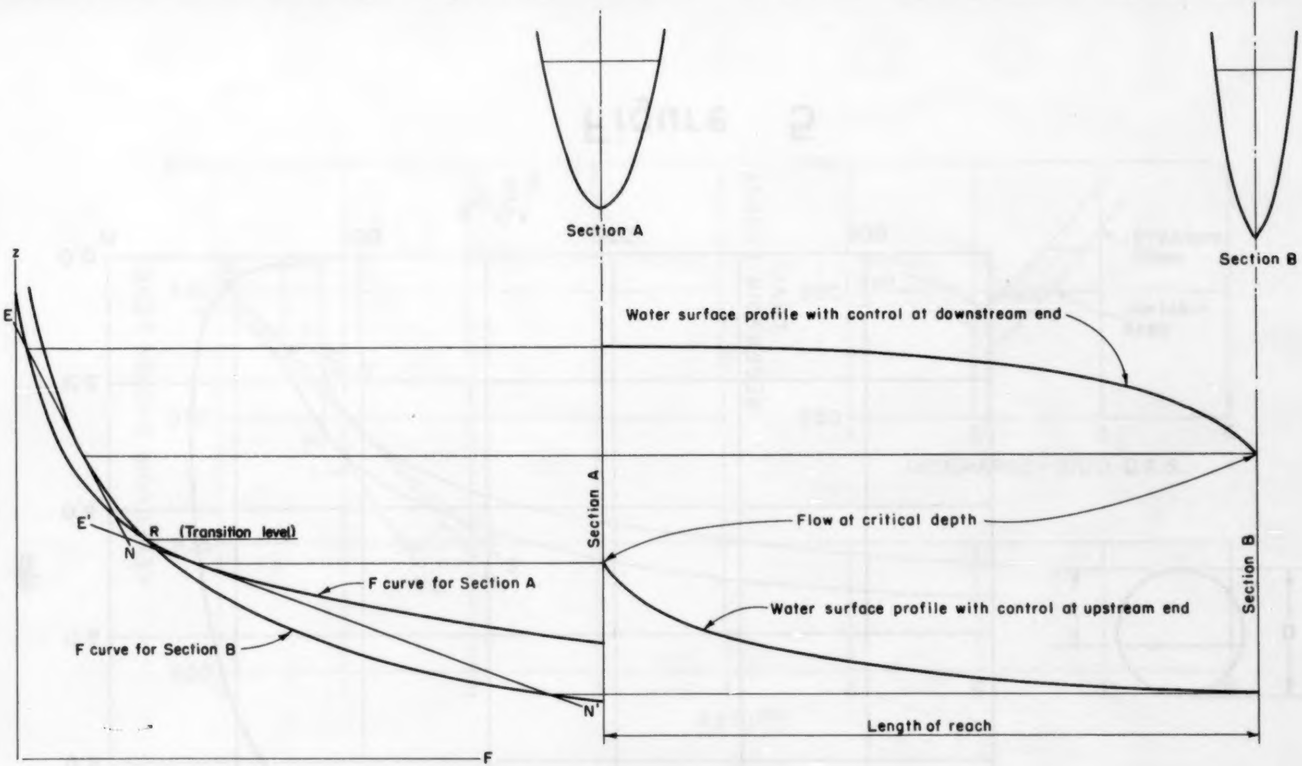
PROPERTIES OF F CURVE

Figure 2



BACKWATER CURVE IN CHANNEL WITH NEGLIGIBLE LOSSES IN ENERGY

Figure 3



TRANSITION LEVEL IN OPEN CHANNEL
WITH NEGLIGIBLE LOSSES IN ENERGY

Figure 4

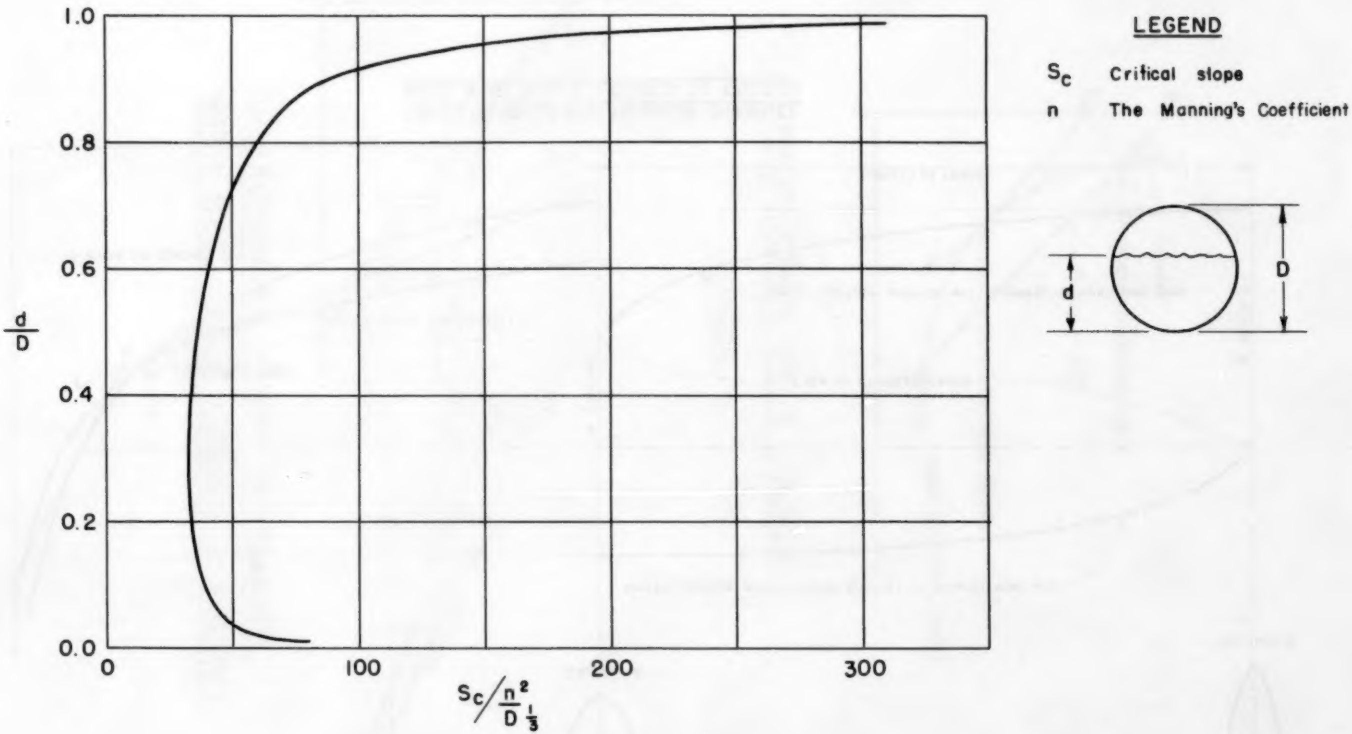
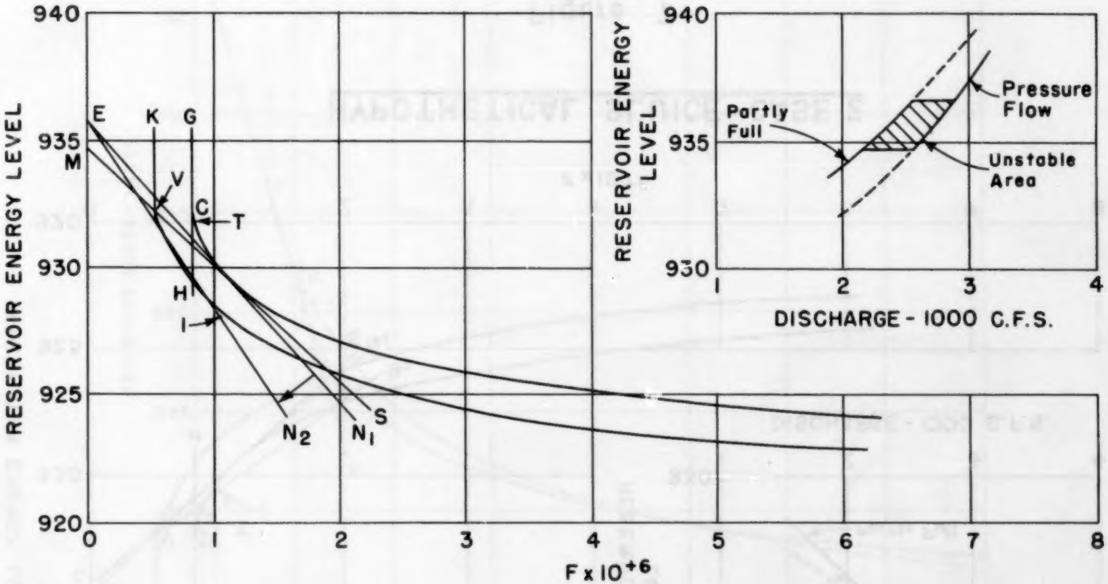
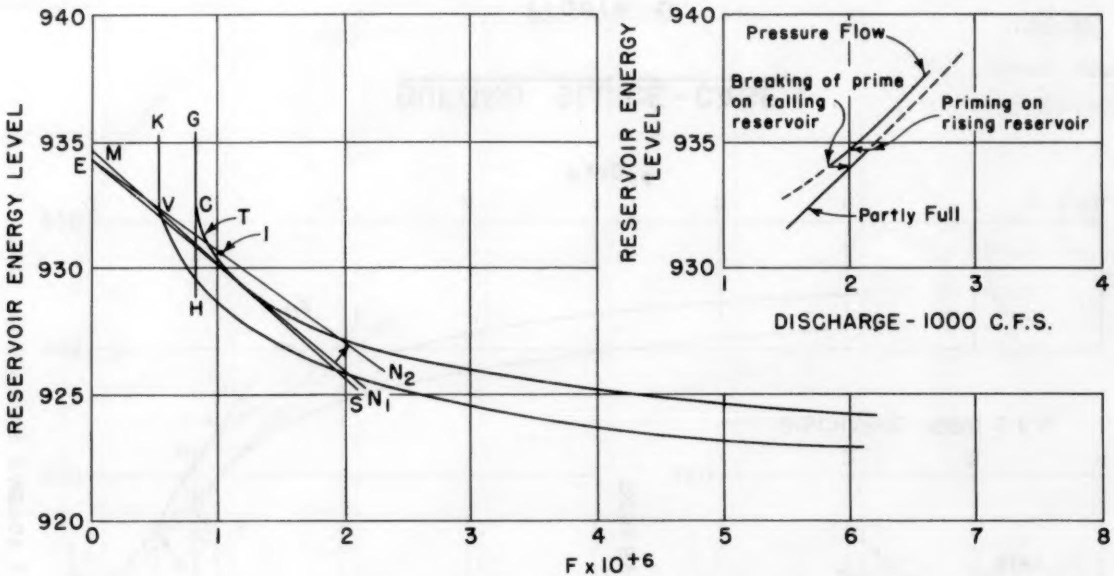

1.0
0.8
0.6
0.4
0.2
0.0
d/D
0
100
200
300
Sc/(n²/D^(1/3))
LEGEND
Sc Critical slope
n The Manning's Coefficient
d
D

Figure 5



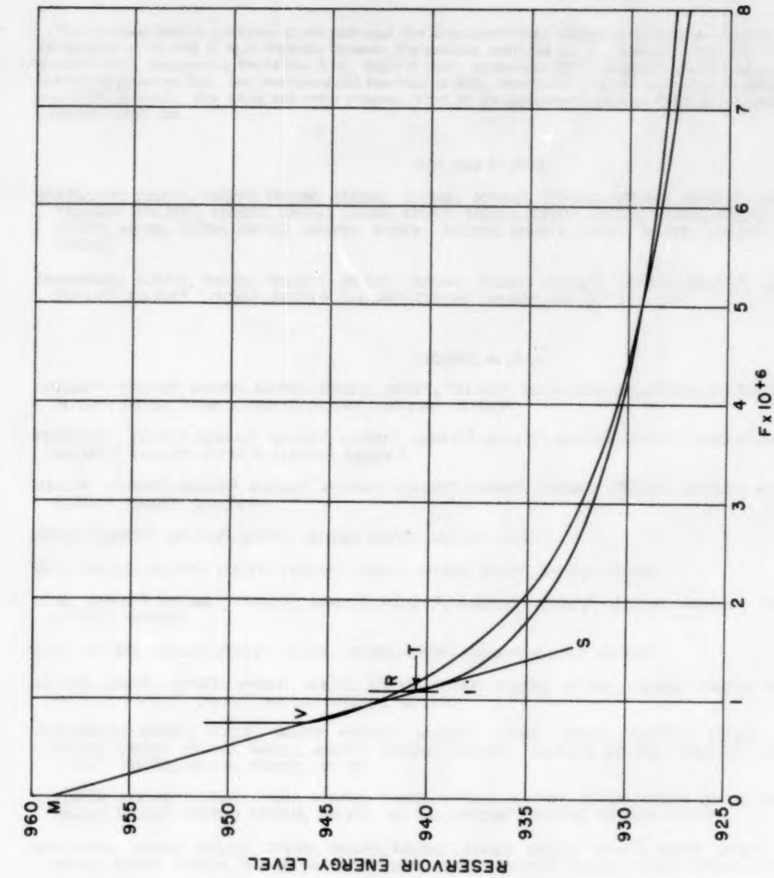
BUFORD SLUICE - CASE I

Figure 6



HYPOTHETICAL SLUICE - CASE 2

Figure 7



PENSTOCKS

Figure 8

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VOLUME 79 (1953)

NOVEMBER: 321(ST), 322(ST), 323(SM), 324(SM), 325(SM), 326(SM), 327(SM), 328(SM), 329(HW), 330(EM)[a], 331(EM)[a], 332(EM)[a], 333(EM)[c], 334(EM), 335(SA), 336(SA), 337(SA), 338(SA), 339(SA), 340(SA), 341(SA), 342(CO), 343(ST), 344(ST), 345(ST), 346(IR), 347(IR), 348(CO), 349(ST), 350(HW), 351(HW), 352(SA), 353(SU), 354(HY), 355(PO), 356(CO), 357(HW), 358(HY).

DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[c], 368(WW)[c], 369(IR), 370(AT)[c], 371(SM)[c], 372(CO)[c], 373(ST)[c], 374(EM)[c], 375(EM), 376(EM), 377(SA)[c], 378(PO)[c].

VOLUME 80 (1954)

JANUARY: 379(SM)[c], 380(HY), 381(HY), 382(HY), 383(HY), 384(HY)[c], 385(SM), 386(SM), 387(EM), 388(SA), 389(SU)[c], 390(HY), 391(IR)[c], 392(SA), 393(SU), 394(AT), 395(SA)[c], 396(EM)[c], 397(ST)[c].

FEBRUARY: 398(IR)[d], 399(SA)[d], 400(CO)[d], 401(SM)[c], 402(AT)[d], 403(AT)[d], 404(IR)[d], 405(PO)[d], 406(AT)[d], 407(SU)[d], 408(SU)[d], 409(WW)[d], 410(AT)[d], 411(SA)[d], 412(PO)[d], 413(HY)[d].

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APRIL: 428(HY)[c], 429(EM)[c], 430(ST), 431(HY), 432(HY), 433(HY), 434(ST).

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OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)[c], 519(IR), 520(IR), 521(IR), 522(IR)[c], 523(AT)[c], 524(SU), 525(SU)[c], 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)[c], 531(EM), 532(EM)[c], 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

a. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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